Development of

A HYDROHANDLING SYSTEM FOR SORTING AND SIZING APPLES

for Storage in Pallet Boxes

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SUMMARY

Studies were conducted to investigate the properties and characteristics of apple fruits related to sizing, sorting, and filling them into boxes, utilizing water as the handling medium; and to design, construct, and evaluate various components on a pilot scale for a hydrohandling system. The findings provided basic information essential for the development of equipment for sorting and sizing apples destined for storage in pallet boxes.

The behavior and characteristics of apples in water and in a water sizing and filling system were determined. As specific gravity of apples is in the range of 0.78 to 0.85, the fruit was buoyant enough to float satisfactorily in water. The fruit orientation (stem up, down, or sideways) at the surface varied by fruit shape and chance as the fruit came to rest at the water surface.

The upward terminal velocity of apples in water was 1.2 to 2.0 feet per second, depending on the variety and size of the apple. This velocity is equivalent to a fall of less than 1 inch in air.

Mechanical submersion of fruit by a rubber conveyor belt, with flights 2 inches in height at an angle of 30° from the horizontal, at speeds up to 60 feet per minute proved satisfactory. Free movement of the submerged apples to the surface served best for the upward movement of apples in water. The angle of repose of submerged apples accumulated underwater in response to buoyant force varied from 30° to 36° depending on fruit variety.

Hydrostatic pressure caused water uptake and tissue damage to submerged apples; however, submergence to depths of 6 feet of water for up to 15 minutes was considered safe. Apples floating at the water surface gained water after 4 hours, but they were not affected in respect to flesh firmness or susceptibility to bruising when held at depths of 2.5 feet for as long as 8 hours.

Existing water flotation dumpers for removal of apples from bulk boxes were considered adequate without further evaluation. Sorting in water to remove defective fruit was given cursory examination but abandoned in favor of modern conventional methods now in commercial use.

Examination of several ideas for sizing submerged apples utilizing their buoyancy showed the chain sizer to be best because of simplicity, high capacity, and positive fruit flow. Fruit damage was limited to chain marks of minor degree and extent for McIntosh apples chain sized underwater with pilot model equipment. A sizing chain with hexagonal openings gave better sizing accuracy than a square-link chain.

Box filling in water was best accomplished by collecting the fruit underwater in an accumulator container and transferring the fruit to the storage container underneath by lifting the containers together from the water. Operation of a pilot model filler of 1-bushel capacity showed that fruit damage was approximately equal to the damage resulting from hand filling.

The success achieved with small-scale pilot model components in sizing and filling boxes would seemingly justify the construction and test operation of a complete prototype system. A layout was prepared for a proposed hydrohandling system to dump, sort, size, and refill pallet boxes at the rate of 600 bushels per hour.

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for Storage in Pallet Boxes

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INTRODUCTION

Apple production, handling, storage, preparation for market, and marketing are integral phases of a dynamic industry which has experienced numerous and radical changes in recent years. Bulk handling, lengthening of the storage and marketing season, and centralization of storage, packing, and sales operations are some of the major developments. Many of the changes were necessary to offset the constantly increasing costs of labor, supplies, and facilities. Further steps toward more efficient operations and better utilization of existing storage facilities are imperative.

The storage of orchard-run apples—as traditionally practiced in many areas—is wasteful because of the loss of valuable storage space; yet presizing and presorting of storage fruit is impractical because of excessive labor requirements and the mechanical damage to the fruit caused by existing equipment.

The inherent value of efficient utilization of storage space by presorting and presizing the fruit is readily recognized. There are less obvious values. Presizing and presorting would provide a means of making an inventory of the fruit by grade, size, and possibly, condition. At the present time orchard-run storage apples are itemized and segregated only by variety, area, orchard of production, or time of harvest. An additional advantage of presizing and presorting is that the method offers a means of recording each grower's share of the various qualities and quantities of fruit at harvesttime rather than at the conclusion of the storage period. This would be particularly valuable with pooled lots.

Modern trends in handling apples have increased the need for presizing and presorting fruit. The use of pallet (bulk) boxes [1] limits the opportunity for fruit sorting by the picker, while at the same time proper supervision of the picking operation has become difficult. Fruit lots of different quality cannot be recognized and separated easily at the storage receiving area.

The large volumes of fruit handled in centralized operations, particularly in areas where the storage and marketing season extends to 6 months or longer, make it almost essential that the range in fruit qualities and sizes be determined before a sound marketing program of sales and deliveries is established.

Dumping and refilling pallet boxes at the storage will require specialized mechanical facilities. The speed and ease with which filled containers can be mechanically handled from the orchard to the storage suggest the need for a high-capacity presizing and presorting operation. Fruit handling at harvesttime at the storage plant need not be con-

[1] Although this report uses the term pallet boxes, these are variously referred to in different areas as bulk boxes, pallet bins, bins, pallet containers, bulk containers, etc. The pallet box used for apples holds 16 to 25 bushels and has approximate outside dimensions of 48 by 40 inches with an inside depth of 30 inches.

fined to small enclosed areas, but could be accomplished outdoors. Capital outlay for the equipment required for presizing and presorting bulk lots of orchard-run fruit is not likely to be economically feasible except where large volumes of fruit are available such as in centralized packing and storage facilities. The need for high-capacity, reliable equipment that can be operated 24 hours per day during the peak of harvest season is obvious for such an operation.

The above considerations, together with the requirement of minimum mechanical damage to the apples, particularly for such soft-fleshed varieties as the McIntosh, have indicated that new concepts of fruit sorting be considered and developed. The success of water submergence devices (*12*, *13*)[2] for dumping apples from pallet boxes suggested water as a likely medium of handling. Studies were conducted, therefore, to investigate the properties and characteristics of apple fruits related to sizing, sorting, and filling into boxes with water as the handling medium; and to design, construct, and evaluate various components for a sizing, sorting, and box-filling system.

Other than the work of Martin (*9*), little has been reported on the development of a complete hydrohandling system suitable for sorting and sizing apples. He developed and built a model hydrobox dumper, sorter, sizer, and 1-bushel box filler in the early 1950's. A patent (*9*) for a helical device for sizing commodities in water was issued.

The need for pallet-box fillers that would handle apples gently enough has been recognized and at least two such fillers have been developed. The one developed by the U.S. Department of Agriculture (*6*) consists of a series of rotating padded disks and cones which are lowered into the pallet box and gradually raised as the box fills. Its capacity is 12 pallet boxes (or approximately 200 bushels) per hour. The Pomona Box Filler (*3*) lowers the fruit into a rotating pallet box by means of a canvas conveyor which automatically rises as the box is filled. Tests with this filler on McIntosh apples in British Columbia (*11*) resulted in some bruising and 4.2 stem punctures per 100 fruits. Both fillers are better suited to the Delicious variety.

APPLE FRUIT CHARACTERISTICS RELATED TO HYDROHANDLING

Several properties and characteristics of apples likely to affect their behavior during handling in water were investigated. They were related to positioning of the fruit in the water, fruit reactions to applied forces of propulsion, and fruit response to buoyancy forces.

Fruit Buoyancy

That the specific gravity of the apple is less than the value for water was recognized and utilized by Pflug and Dewey (*12*) in developing the water submergence dumper. A more exact knowledge of fruit specific gravity and its variations was employed by Porritt, McMechan, and Williams (*14*) in developing an alcohol-water separation system for removing apples with the water core disorder. The data of Cooper[3] for Pennsylvania apples and of Westwood (*15*) for Oregon apples show that the specific gravity of apples at time of harvest ranges by variety and by location of production area from 0.78 to 0.85 (table 1). These values mean that apples float in water with about four-fifths of the fruit submerged.

TABLE 1.—*Specific gravity at harvesttime of varieties of apples grown in Pennsylvania and Oregon, 1961 season* [1]

Variety	Pennsylvania	Oregon
Delicious	0.83	0.85
Golden Delicious	.81	.81
Jonathan	----------	.78
McIntosh	.81	----------
Rome Beauty	----------	.83

[1] Data for Pennsylvania are from Cooper (see footnote 3 and for Oregon from Westwood (*15*).

[2] Italic figures in parentheses refer to Literature Cited, p. 31.

[3] COOPER, H. E. INFLUENCE OF MATURATION ON THE PHYSICAL AND MECHANICAL PROPERTIES OF THE APPLE FRUIT. Pa. State Univ. M.S. thesis (unpublished). 1962.

Surface Orientation

Studies of the position in which apples float were conducted with McIntosh, Delicious, and Jonathan apples in still water, moving water, and still water with fruit mechanically translated. One-bushel crates were filled with fruit placed at random in the crate. The crates were submerged in a tank of water in an upright position. Water movement of 150 feet per minute at the surface was provided by a circulation pump. A hand-propelled framed screen was employed for mechanical translation of fruit in still water.

The marked differences in floating orientation by fruit variety are illustrated by the data of table 2 for apples in still water. Jonathan apples seldom floated stem down and infrequently on their sides, whereas about two-thirds of the McIntosh floated stem up, one-third stem down, and a few floated on a side. Delicious floated either stem up or on their sides.

TABLE 2.—*Floating orientation of apples in still water*

Variety and year	Sample size	Stem up	Stem down	Cheek up
Jonathan:	*Fruits*	*Percent*	*Percent*	*Percent*
1962	875	95	1	4
1963	139	91	8	1
McIntosh:				
1962	965	64	34	2
1963	164	60	39	1
Delicious:				
1962	924	71	2	27
1963	100	75	17	8

Orientation in water was affected by fruit shape and by the relative dimensions parallel and at right angles to the stem-calyx axis of the fruit. The floating procedure offers the possibilities of a simple method for readily evaluating fruit by form or shape. Jonathan were typically roundish conic to roundish ovate, McIntosh roundish to somewhat oblate with the axial diameter generally less than the equatorial diameter, and Delicious were conic in shape with 73.4 percent having the axial dimension greater than the equatorial dimension.

The somewhat oblate form of McIntosh suggested that chance might also affect the orientation of fruit at the water surface. To investigate this, a sample of McIntosh composed of 193 fruits, which all floated stem down after submersion dumping, were returned to the water after random positioning in a bushel crate. Only 64 percent floated stem down this time, and 33 percent floated stem up. Tests conducted in another year (1963) with McIntosh gave similar results. Chance was less a factor with Delicious and Jonathan. The fruit of the Delicious variety which originally came to rest stem up (1963) ranged from 80 to 86 percent stem up when subsequently returned to water three additional times. The range of stem up for Jonathan was 87 to 92 percent in subsequent trials.

Apples that were misshapen often floated on their sides, with the side of least volume downward. There was no marked effect on fruit orientation as a result of fruit movement.

Buoyant Velocity

If water is used as a handling medium in an apple sorting and sizing system, it should reduce fruit bruising over conventional methods. Since buoyant velocity has a direct effect on bruising, values were obtained to estimate the impact of an apple upon contact with an object in or just above the water.

The apparatus used for ascertaining buoyant velocities is shown in figure 1. Each fruit was released from rest at the bottom of the container and its upward movement filmed. The movie enabled the plotting of displacement versus time,

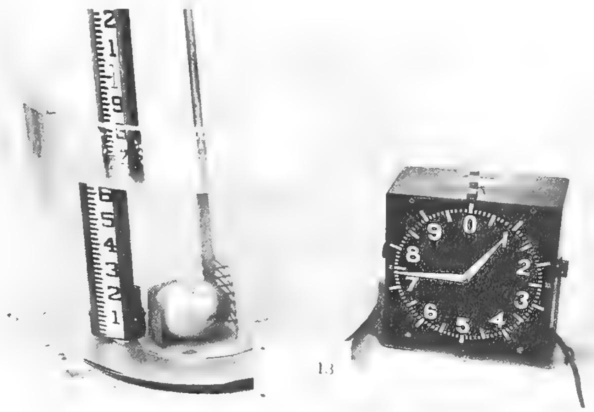

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FIGURE 1.—Apparatus for measuring buoyant velocity of apple fruit submerged in water. Fruit movement and time were recorded on film by movie camera.

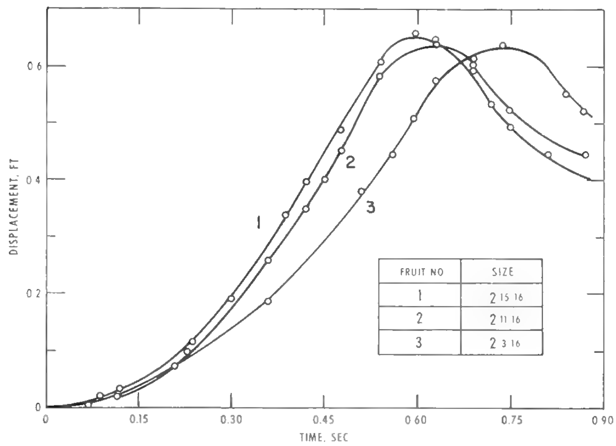

FIGURE 2.—Buoyant velocity in water for McIntosh apples of three sizes (diameter, inches) from rest (0) to surface (0.65 foot).

from which velocity could be determined by differentiation (fig. 2). The pertinent data and calculations are given in table 3.

A rubber ball was used to compare the experimental and theoretical velocities of a sphere. The theoretical velocities apply to spheres in an infinitely large container. The experimental values were lower due to the wall effects of the 15-inch-diameter container. The rubber ball tests permitted evaluation of the wall effect of the container.

The corrected velocities in table 3 were obtained by multiplying the actual velocities by 1.06, the wall correction factor (F_1). Each corrected velocity value in table 3 is the predicted terminal velocity for the fruit in an infinitely large tank.

There was considerable difference between the corrected and theoretical velocities of the fruits, apparently due to the use of an inaccurate drag coefficient in the theoretical velocity calculations. The drag coefficient for a perfect sphere was used, but the stem and nonspherical shape of the fruit resulted in a higher drag coefficient. The F_2 values in table 3 are the correction factors which made the theoretical and experimental results coincide. The drag coefficient for apples in water with the stem pointing in the direction of motion can be developed from the correction factor F_2.

A reasonable estimate of F_2 for apples is 0.8 (table 3). Using this value, $C_a=1.56C_s$, where:

C_a=the drag coefficient for apples

C_s=the drag coefficient for spheres

For the turbulent flow conditions in this experiment, $C_s=0.44$, the coefficient of drag for apple fruits is equal to $(1.56)(0.44)=0.68$. This value for the drag coefficient was determined from a limited number of tests and should be confirmed by additional tests using different sized containers and larger samples of fruits released from several depths.

A curve for displacement versus time showed that apples reach their terminal buoyant velocity after 2 to 3 inches of travel. The short distance of acceleration indicated that in predicting bruise damage resulting from fruit contact with objects underwater, the terminal velocity should be assumed.

TABLE 3.—*Terminal buoyant velocity of apple fruits in water*

Variety and replication	Average diameter perpendicular to core axis	Specific gravity	Actual velocity	Corrected velocity [1]	Theoretical velocity [2]	Correction factor (F_2)[3]
McIntosh:	*Inches*	*Value*	*F.p.s.*	*F.p.s.*	*F.p.s.*	
1	2. 94	0. 761	1. 83	1. 94	2. 340	0. 829
2	2. 66	. 754	1. 70	1. 80	2. 165	. 831
3	2. 19	. 797	1. 36	1. 44	1. 915	. 752
Delicious:						
1	2. 84	. 818	1. 59	1. 68	1. 940	. 866
2	2. 69	. 795	1. 56	1. 65	2. 210	. 746
3	2. 44	. 833	1. 15	1. 22	1. 840	. 663

[1] Actual velocity multiplied by F_1 (1.06), the wall correction factor.

[2] Velocity of a perfect sphere in an infinitely large container of water.

[3] Corrected velocity (Vc) divided by the theoretical velocity (Vt).

A hydrohandling system will substantially reduce fruit bruise damage because of the low buoyant velocity compared to the velocity attained in an air drop. Table 3 shows that the highest velocity which a large McIntosh fruit attained in water was 1.94 feet per second (f.p.s.). This is equivalent to a 0.7-inch fall in air and can cause a slight bruise (*5*). Therefore, the areas of equipment that fruit may contact after floating up more than 2 inches should be covered with a cushioning material to prevent bruising of the fruit.

Dropping apples in water from several heights showed that a considerable depth of water is needed to completely cushion falling fruit. Fruits sank to an average depth of 7 inches when dropped from a height of 2½ inches; as expected, the relation between height of drop and depth of sinkage was not a linear relationship. Fruits dropped from 3 feet above the water sank only 18 inches. Cushioning materials should be used in combination with water if the depth of water is not adequate to completely decelerate the fruit before it contacts another object.

Fruit Submersion

The submerging characteristics of apples were examined to ascertain the possible ways in which their natural buoyancy could be utilized in designing equipment to carry the apples beneath the water surface. For these studies, the laboratory test tank was equipped with plexiglass windows on the side and bottom to enable observation of the fruit underwater. A flighted rubber belt mechanism (fig. 3), 5 feet long and 18 inches wide, with 2-inch flights spaced 10 inches apart, was mounted in the tank in a manner to allow adjustment of the angle of incline. It was powered by a hydraulic motor so the speed of movement of the belt was adjustable up to 100 feet per minute (f.p.m.). When employed at a 30° angle from horizontal, there was good pickup of fruit for the three varieties tested—Jonathan, McIntosh, and Delicious. The water currents developed by the flights pulled additional fruit to the pickup area. The apples were carried downward with little rollback by the 2-inch flights at

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FIGURE 3.—Flighted rubber belt mechanism for submerging fruit in water.

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FIGURE 4.—Pyramid of fruit resulting from the accumulation of apples underwater.

belt speeds up to 60 f.p.m. Higher speeds of translation caused the apples to roll to at least one other flight. Although fruit handling was gentle at belt speeds up to 80 f.p.m., the overall performance was best at 60 f.p.m. At 65 f.p.m. a 36-inch-wide belt having a 6-inch flight spacing would have a capacity of 750 bushels per hour. The maximum angle of incline of a conveyor with 2-inch perpendicular flights was 30°, but flight shape and height could be designed for operation at greater angles.

Cylindrical plexiglass tubes constructed with inside diameters of 3 inches and 3¾ inches, and a plexiglass tube of rectangular cross section, adjustable to dimensions of either 3 by 10 inches or 8 by 10 inches, were tested as submergence devices. A positive water flow through the tubes was utilized to propel the fruit.

The tests showed that a tubular submerging device must have a diameter which fits the apples quite closely. Effects of loose fit were especially noticeable in suction-generated velocity tests. For apples 2½ to 2¾ inches in diameter, a 3-inch tube performed considerably better than a 3¾-inch tube. An 8-by-10-inch rectangular tube was unsatisfactory because of the large quantities of water required to provide the necessary velocity.

The force required to submerge apples vertically through a tube was found to be approximately 70 percent of the total fruit weight. Buoyant force accounted for 20 percent and wall friction for 50 percent of the total fruit weight. Wall friction decreased with increased fruit size for a given diameter tube. Small fruits tended to wedge sideways in the tube, whereas large fruits rested on each other and thereby wedged less severely.

Angle of Repose of Accumulated Fruit Underwater

The positioning behavior of apples accumulated underwater in response to buoyant forces was examined in conjunction with the submerging studies.

The angles of repose during underwater pyramiding (fig. 4) for the three apple varieties, as averages for three replications, are listed in table 4. Angles of repose of apples in air as held by gravitational forces varied from 40° to 50° for Delicious and Jonathan apples ranging from 2½ to 3 inches in diameter.

TABLE 4.—*Angles of repose for apples accumulated and held by buoyancy underwater*

Variety	Fruit diameter	Angle of repose
	Inches	*Degrees*
Jonathan	2½	30
McIntosh	2¾	33
Delicious	3	36

The angles of repose of submerged fruit indicated that the design of an underwater filling device must provide adequate space allowance for fruit pyramiding or utilize a distributing device to provide a level fill of fruit in the accumulator.

Fruit Movement on Inclined Surfaces by Sliding or Rolling

A simple means of transporting submerged apples would be to allow them to roll up an inclined plane. Consequently, values describing the ease of sliding or rolling of several varieties in contact with a submerged inclined surface were obtained. Similar values for apples moving down surfaces in air were obtained for comparative purposes.

Unlike a spherical or cylindrical object, a fruit began rolling from its equilibrium position whenever the line of action of its weight advanced beyond the surface contact point. This made the conventional definition of rolling resistance invalid in its application to nonspherical fruits. In the absence of standards for expressing the rolling resistance of fruits, the average angles of incline (θ) were used (fig. 5).

Five surfaces were used: (1) Wood, (2) galvanized metal, (3) canvas belting, (4) expanded polyethylene, and (5) polyurethane. A surface covered with one of the five materials was attached between the plexiglass sides of the device shown in figure 5.

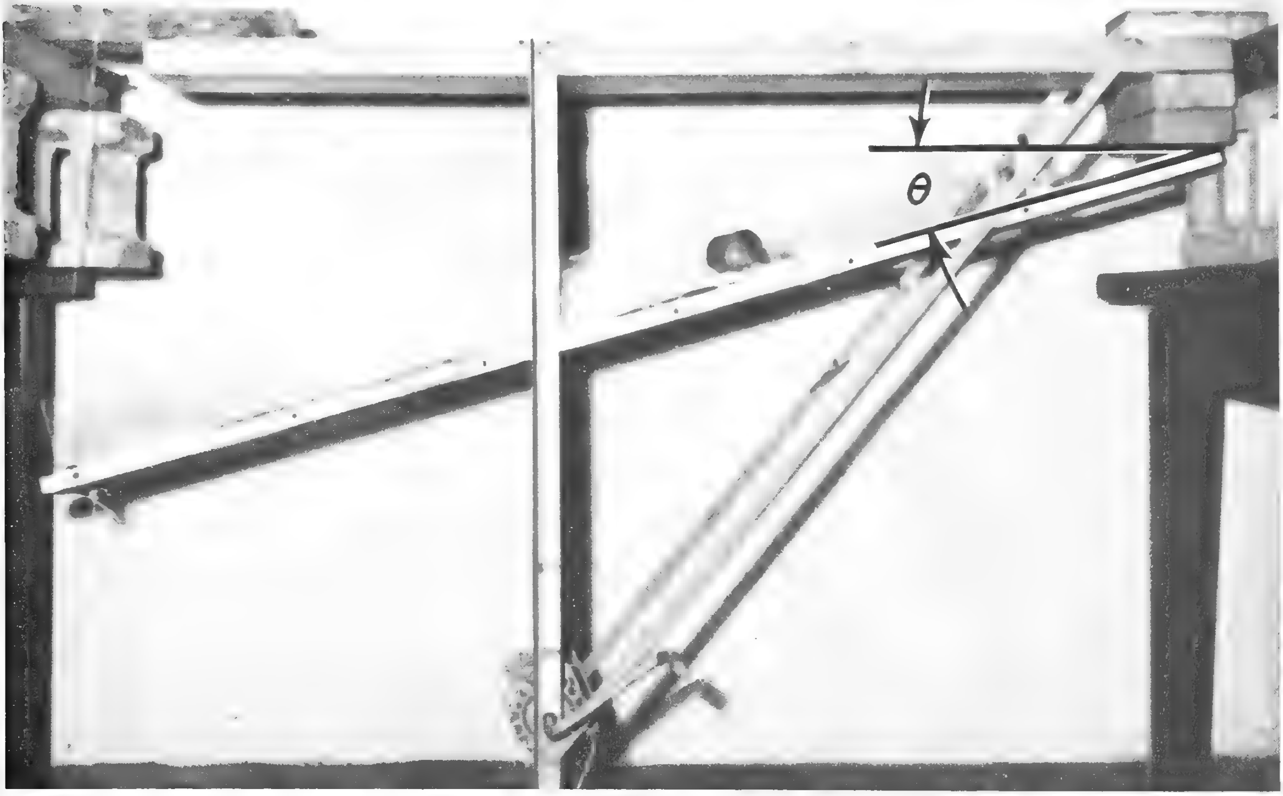

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FIGURE 5.—Device used for determination of the rolling and sliding resistance of apples. The device was inverted for underwater tests. (The apple would roll against the upper surface underwater.)

Both static and dynamic tests were made under sliding and rolling conditions. For the static sliding tests the apple was placed on the surface in its equilibrium position. The angle of incline (θ) was gradually increased until the fruit began to slide. The minimum angle at which the fruit would slide was recorded as the angle of static friction. A wire bracket prevented rolling.

For the dynamic friction tests the apple was set in motion on the inclined surface. The minimum angle at which the apple would continue to slide at a constant velocity was recorded as the angle of dynamic friction.

The rolling resistance tests were conducted in a manner similar to the sliding friction tests except that the fruits were allowed to roll.

The variations in rolling resistance between the surfaces were small, but there were large variations between fruit varieties (table 5). McIntosh had a much higher angle of static rolling resistance than Delicious and Jonathan varieties because of dissimilar equilibrium positions.

The equilibrium position was defined as the most frequently assumed position of each fruit after being rolled on a level surface. The equilibrium position for McIntosh fruits was on the calyx while the equilibrium position typical for the Delicious and Jonathan varieties was on the side.

TABLE 5.—*Average angles (degrees) of rolling resistance and sliding friction of apple fruits in air and water*

Item	Delicious	Jonathan	McIntosh
Angle of rolling resistance:			
Air:			
Static	10. 1	8. 0	15. 0
Dynamic	2. 5	2. 1	2. 1
Water:			
Static	12. 1	9. 6	15. 8
Dynamic	5. 2	4. 8	4. 5
Angle of sliding resistance:			
Air:			
Static	20. 6	21. 6	21. 6
Dynamic	18. 4	20. 8	21. 2
Water:			
Static	24. 9	26. 1	26. 6
Dynamic	25. 1	26. 4	26. 6

The angles of static rolling resistance in air and underwater were approximately equal. The angle of dynamic rolling resistance was approximately 2.5° greater underwater than in air. Although fluid resistance probably had some influence on the magnitude of the angle in water, it was minimized by rolling the fruits just fast enough to prevent their stopping on the calyx or stem cavity.

The angle of sliding friction varied only slightly with fruit variety and with the type of surface, except for the expanded polyethylene which had approximately a 20-percent greater angle than wood, metal, and canvas surfaces.

The angle of sliding friction in all cases was approximately 20 percent greater in water than in air.

Water Penetration of Fruit

Delicious and McIntosh fruit were compared for possible water uptake during handling in water. Fruits of the Delicious variety frequently have an open calyx canal, which could permit the entrance of water to the seed cavity. McIntosh apples have a closed canal.

Static pressure tests were made using a retort to provide constant pressures up to 30 pounds per square inch (p.s.i.) on submerged fruit. Ten apples of each variety were treated at five pressures. Weight changes were observed after 1, 5, and 15 minutes of pressure treatment. The water was maintained at room temperature (72°–78° F.)

The results are plotted in figure 6. Pressure, time, and maturity were contributing factors to the amount of water forced into the fruit. McIntosh fruits took up very little water, probably because of a closed calyx tube. Delicious fruits gained appreciably greater amounts of water.

Sectioning of the Delicious fruits after the tests revealed several patterns of water saturation in the flesh tissues. Saturated areas often radiated outward from the core into the cortex, but areas near the skin were often saturated without an apparent water path from the core. Removal of the fruit skin before the test greatly increased the area of saturation. The cell structure was apparently disrupted in the saturated area as evidenced by a soft flesh texture similar to that caused by severe mechanical bruising.

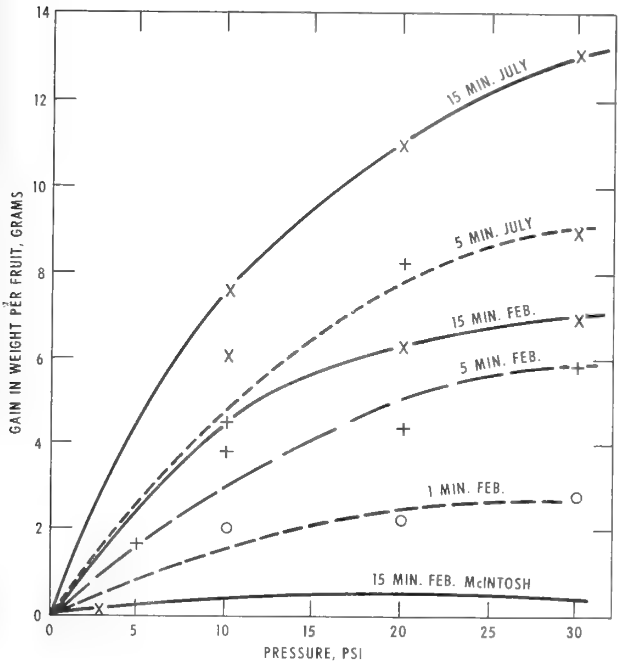

FIGURE 6.—Water uptake of submerged apples in relation to duration of application of hydrostatic pressure. The bottom curve (15 min. February McIntosh) is for McIntosh apples harvested in the fall and stored to February prior to testing. The other curves are for Delicious harvested in the fall and stored for testing in February or July.

Fall-harvested fruit absorbed nearly twice as much water when tested the following July as when tested in February, which suggests that the degree of ripeness affects water penetration.

These results suggest that the low hydrostatic pressures on fruit submerged 0 to 6 feet (below 5 p.s.i., fig. 6) for hydrohandling present no problem of water penetration even for the Delicious variety.

The effects of holding Delicious apples in water for various durations of time and at several depths of submergence were examined in April 1964 with apples from cold storage. The fruits were warmed to room temperature. Test lots of 20 apples, ranging in size from 2¼ to 3¼ inches, were placed in water at the surface, at a depth of 1 foot below the surface, and at a depth of 2½ feet, for 1, 2, 4, and 8 hours. The water was at room temperature. Two controls were employed: One test lot was not placed in water while the other was submerged and immediately removed. After treatment, all fruit was held at 70° F. for 5 days and subsequently examined for exterior and interior conditions and tested for flesh firmness with a pressure tester. The results are summarized in table 6.

No consistent effect upon flesh firmness was found as a result of holding the apples in water. It was observed that fruit held in water for 4 hours or more showed water uptake as indicated by a water-soaked appearance adjacent to the seed cavities and the epidermis. This means that relatively long durations in water for apples of this age (approximately 6 months after harvest) should be avoided.

The susceptibility of McIntosh apples to bruising, as a result of handling in water, was also examined in respect to the depth of submergence of the fruit in water and to the duration of time in water.

Bruise-free fruit harvested September 15 and stored at 32° F. were employed for this test, which was conducted in early November. Apples of

TABLE 6.—*Flesh firmness and condition of Delicious apples following water submergence treatments and holding for 5 days at 70° F., April 1964*

Duration and depth of submergence	Average fruit firmness	Notes on fruit condition
Controls:	*Pounds*	
Dry	12.7	Good.
Wet	12.8	Do.
1 hour:		
Surface	12.4	Good.
1 foot	11.9	Do.
2.5 feet	12.6	Do.
2 hours:		
Surface	12.4	Good.
1 foot	12.4	Do.
2.5 feet	12.8	Do.
4 hours:		
Surface	12.8	Good.
1 foot	12.5	Slight water congestion at core and beneath epidermis.
2.5 feet	12.6	Do.
8 hours:		
Surface	12.8	30 to 50 percent of apples with water congestion at core and beneath epidermis.
1 foot	12.6	Do.
2.5 feet	12.4	Do.

uniform size (2¾ to 3 inches diameter) and shape were selected and 10 were assigned at random to each treatment lot. The average flesh firmness was 13.7 pounds, as tested with a $\frac{7}{16}$-inch plunger on the pressure tester. The apples were warmed to 70° F., the water temperature, prior to treatment. Treatments consisted of submergence of the apples at the water surface and at depths of 1 and 2.5 feet for periods of 0, 0.25, 0.75, 1, 2, 3, 4, 5, 6, and 8 hours. The apples were bruised (one bruise per fruit) immediately upon removal from the water. A weighted board mounted on a fulcrum was dropped a fixed distance onto the cheek of the fruit. The apple was held in a sand bed to provide a firm surface of variable height to accommodate the fruit of slightly variable size and shape.

The diameter of the bruised area was measured after a holding period of 48 hours at 70° F. The diameter of the bruise area averaged 0.67 inch and ranged from 0.5 to 0.9 inch. No significant differences in the size of the bruise area due to time or depth in water was found.

A condition of water congestion in the cortex tissues adjacent to the skin was observed in some apples held 6 or 8 hours in water. This condition was similar to that observed in Delicious (see above), except that none appeared in the core area of McIntosh.

Conclusions

The specific gravity of the mature apple fruit permits it to float about four-fifths submerged in water, which is adequate for most hydrohandling operations. The normal position of fruit in water is either stem or calyx upward, depending primarily upon fruit shape, which is a varietal characteristic.

Submerged fruits, upon release from rest, reach a maximum buoyant velocity of 2 f.p.s. after 2 to 3 inches of upward travel in water. This is equivalent to a fall of 0.7 inch in air. The resultant impact against a hard surface at this rate of travel may cause bruising; therefore, handling equipment contacted by apples upon free buoyancy of 2 inches or more should be covered with a cushioning material.

Fruits dropped into water sink a considerable depth before returning to the surface. An average depth of 7 inches is reached following a 2½-inch air drop, and 18 inches after a 3-foot air drop.

A flighted rubber belt is more satisfactory for submerging fruit, such as into a filling device, than systems utilizing a forced flow of water. The maximum belt speed is about 60 f.p.m. and the maximum angle of incline is 30°.

The angle of repose of submerged apples accumulated underwater in response to buoyant forces is between 30° and 36°, depending on variety. In designing an underwater filling device, the angle of repose will determine the space which must be allowed for fruit pyramiding.

Static rather than dynamic rolling resistance and sliding friction should be used in design calculations if inclined surfaces are utilized for horizontal movement by buoyant forces. These surfaces should be inclined at least 18° for rolling fruit, and at least 30° for sliding fruit.

The submergence of apples may force water into the fruit; however, holding at a 6-foot depth for up to 15 minutes should not be damaging. Holding in water, even at the surface, in excess of 4 hours causes water uptake by the fruit, but has no effect on flesh firmness and susceptibility to bruising.

COMPONENTS FOR A HYDROHANDLING SYSTEM

A complete hydrosystem for the operations involved in prestorage handling of apples would consist of the following major components: (1) Dumper, (2) sorting table, (3) sizers, and (4) pallet-box fillers. Other minor operations, such as removing leaves and trash and filling utility and cider fruit into boxes, were not investigated but were considered in the planning and layout of the system.

Box Dumper

Water flotation dumpers for unloading apples from pallet boxes, although of recent development (*12*), are available from a number of equipment

manufacturers and have been widely accepted by apple handlers. They vary in design, but utilize the principle of vertically submerging a bulk box of fruit in a tank until the top of the box is about 6 inches below the surface of the water. A forced current of water carries the floating apples away from the box to a conveyor or other device for their removal from the water tank. The constant water level essential in a submergence tank is usually attained by employing a weir at the conveyor end of the tank. Provision must also be made for trash removal as the water is circulated through the system. Several types of water dumpers are described by Pflug and Levin (*13*).

The submergence dumper was conceived as a means of removing soft-fleshed apples from pallet boxes with a minimum amount of mechanical injury to the fruit. The effects on McIntosh apples of unloading by the water system and by systems that unload pallet boxes of fruit without water through a gate by tilting or partially inverting the box have been reported (*1*, *2*, *10*). These studies show the primary advantage of the water system to be in the reduction of stem punctures, with perhaps slightly less bruising as well. The demand for washed fruit has also stimulated an increased use of the water dumper.

A water flotation dumper of current design seems satisfactory, and is recommended for a hydrohandling system of preparing apples for storage.

Sorting Devices

Two devices were given cursory examination for sorting fruit in water to remove defective fruit. The first consisted of a series of parallel belts, 3 inches wide, with a 2-inch belt between each pair. These belts, when operated slightly below the water surface and with adjacent belts running at different speeds, should simultaneously provide fruit translation and rotation. The worker forced defective fruit downward between the flexible belts. The second device was constructed of cylindrical nylon brushes of the type used in wet brushers. They were mounted at various spacings in place of the wooden rollers of a sorting table to permit the defective fruit to be removed by submerging between the brushes.

Both devices were unsatisfactory because of the difficulty of submerging an individual fruit without carrying other sound fruit along and because of the need for close spacing of the belts or brushes to prevent the loss of small fruit. Considerable refinement in the water sorting system seemed essential if it was to be used; therefore, although potentially sound in principle, it was abandoned in favor of existing out-of-water sorting equipment.

Methods and equipment for sorting apples in air have been markedly improved in respect to speed and efficiency (*7*). Although modifications of existing systems to water were considered, they were not emphasized in these studies since it is believed that apples can be elevated from water for sorting and easily returned without great risk of fruit damage. Furthermore, the possibilities of sorting apples in water are limited due to reduced visibility and worker discomfort.

Sizing Devices

The basic studies of apple fruit buoyancy indicated that the upward movement of submerged fruit toward the surface was of adequate force and speed for separating fruit of different sizes. Such movement also seemed to be gentle so that collisions of the fruits with each other or with firm surfaces would cause little mechanical injury to the fruit. Several devices were examined for the underwater sizing of apples.

Apparatus

All sizing devices were tested in still water because each device utilized only buoyant force for sizing. The sizing devices tested were: (1) Slat, (2) roller, (3) helical, and (4) chain.

The slat sizing device (fig. 7) consisted of tapered slats submerged and inclined 20° so that buoyant force caused the fruits to roll up the incline until the slat spacing became great enough to permit fruits to pass upward. Sizes were separated by placing partitions perpendicular to the slats near the water surface.

The roller sizing device (fig. 8) operated on the same principle as the slat device. The slats were replaced by rollers which were rotated at different

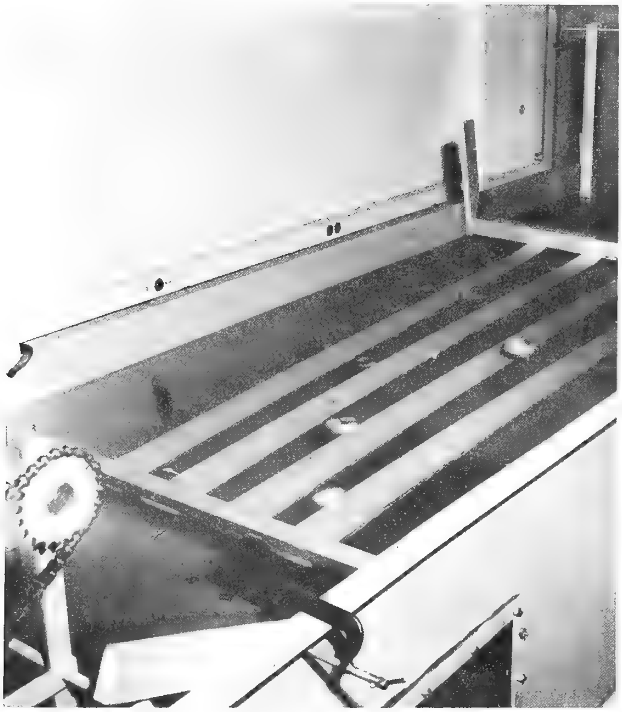

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FIGURE 7.—Experimental underwater sizing device of tapered slats inclined at a 20° angle. The apples placed beneath the slats at the lower left of the photo rolled upward against the slats until the spacing permitted passage to the surface.

speeds. The roller in a pair which turned down against the fruit was rotated twice as fast as the roller which turned upward against the fruit. Size partitions were used in the same manner as with the slat device.

The helical sizer (*8*) shown in figure 9 was operated in a completely submerged position with size partitions at the water surface perpendicular to the axis of the device. Fruits were introduced inside the 8-inch-diameter helix, and the helix rotation carried them horizontally until their dimension permitted passage between the helix coils.

Chain sizer tests were conducted with the device shown in figure 10, using the three chains shown in figure 11. The sizer was mounted in the laboratory test tank on a 15° incline so that the chain carried floating fruits below the surface. Buoyant force then caused the fruits smaller than the chain openings to float upward through the chain links where they were collected after each trial. (Fruits larger than the openings pass under the sizer and float up on the other side of it.)

Performance Tests

Each device was tested using a sample of 20 fruits of each variety with eight replications. The sample was sized into three categories with the slat, roller, and helical devices. Before the test each fruit was measured at the greatest diameter and numbered. The same 20 fruits of each variety were used for all tests with these three sizers. Since the chain sizer separates fruit only into two sizes, the fruit sample used for testing the chain sizers was selected so that fruit size was nearly equal to the chain size. Little would be learned if very small fruits, which could readily pass through the openings, or very large fruits, which obviously could not go through the openings, were used. The slat and roller devices were tested at various angles of incline ranging from 14° to 26°. The helical device was operated at 24 revolutions per minute (r.p.m.). Chain sizers were operated at three speeds: 25, 35, and 46 f.p.m.

Results and Discussion

Results for the four types of sizers are shown in figure 12.

Sizer evaluation was first made using all three size categories, but consideration was given only to the medium size for presentation here. This allows the device to make errors in both directions. Evaluation of the chain sizer was based on the number of fruits passing through the chain links rather than on the number carried under the device. All four devices were quite accurate, with the chain sizer being superior (fig. 12).

Accuracy was quite good for the slat sizer in spite of the fact that it inherently sized McIntosh fruit by the smallest or longitudinal rather than the largest or transverse dimension. If the ratio of small to large diameter is relatively constant for a given variety, an operator could compensate for this sizing orientation and improve accuracy. The major problem encountered was fruit wedging between the slats; as many as 7 of the 20 fruit wedged in several trials. When one fruit wedged,

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FIGURE 8.—Experimental underwater sizing device utilizing inclined rollers with entry of apples at the lower left of the photo.

it interrupted the entire operation because all other fruits in that slot were blocked. A positive carrying mechanism to prevent stoppage would likely cause bruising, because the wedged fruits would be forced from between the slats.

The roller sizer was devised in an effort to eliminate the wedging problems experienced with the slat sizer. Most wedging was eliminated, except for irregular, angular-shaped fruits (especially Delicious) which start to pass between the rollers and then turn to a larger dimension. This caused very severe bruising. The accuracy was fairly

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FIGURE 9.—Experimental underwater sizing device of helical design raised for photographing from the submerged operating position. The apples enter at the right and move to the left until they pass between the helix coils.

good and, unlike the slat device, size was based on the largest dimension of the fruit. The rotation of the rollers caused the McIntosh fruit to rotate with the core parallel to the axis of the roller, and the incline of the rollers caused translation so that size was based on transverse dimension of the fruit.

The helical sizing device had several defects. Fruit wedging was the most serious fault. This might be expected from results of the slat sizer tests, since these devices operate on the same general principle—the helical having a circular rather than linear tapered opening. Like the slat device, it sized McIntosh fruits by the small dimension. The magnitude of sizing error was the largest of all devices tested. Its potential capacity is very limited, even if the sizer diameter were increased to 24 inches, which is possible. Multiple units could be used, but this would complicate the introduction of the fruit into the submersion tank.

The square-link chain sizer was repeatedly ac-

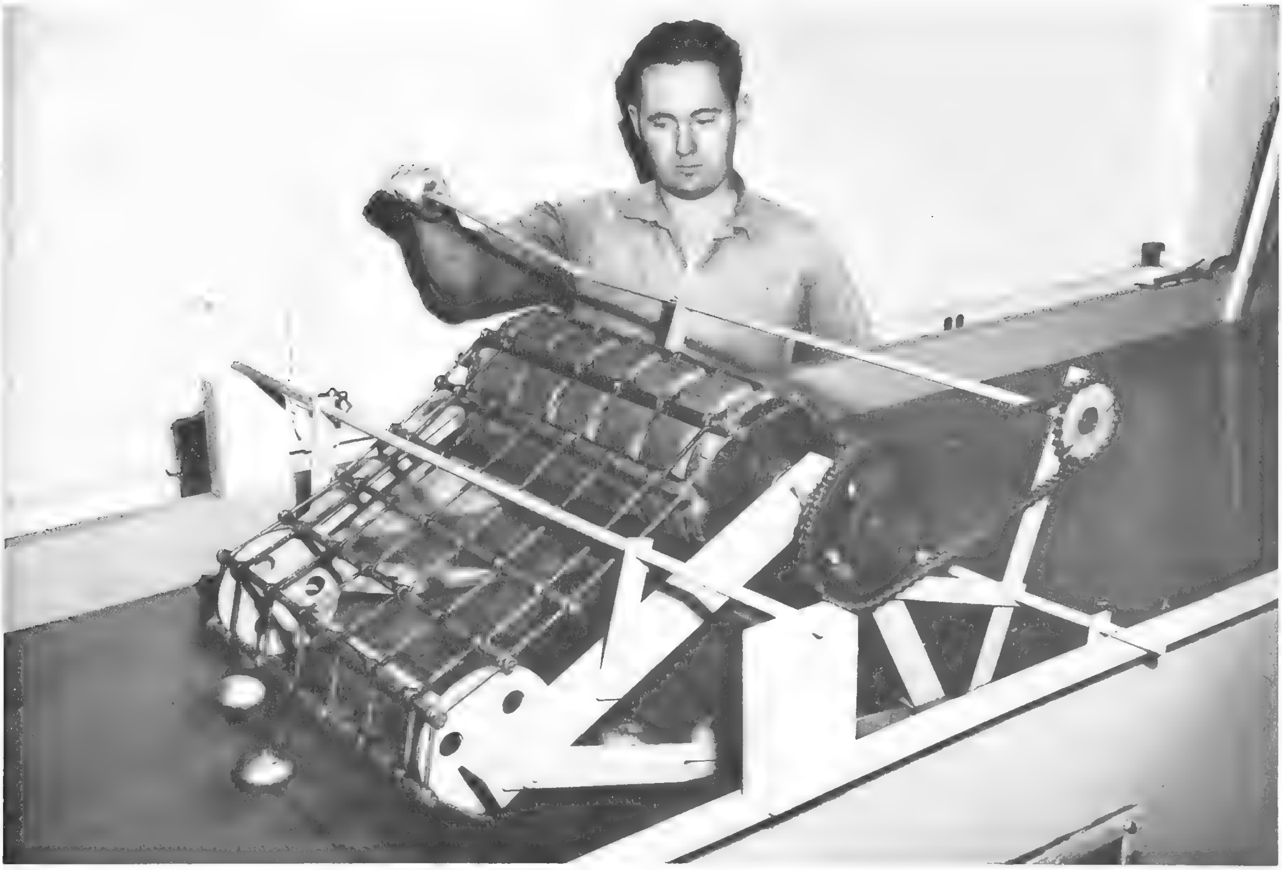

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FIGURE 10.—Chain device in operating position for underwater fruit sizing. The apples enter at the left and are carried underwater by the chain. Small fruits pass through the openings and the large fruits return to the water surface at the right of the device.

curate with only minor wedging problems, which could be easily solved. McIntosh fruits sometimes passed diagonally through the square links so that $2\frac{3}{4}$-inch-diameter fruits passed through the $2\frac{5}{8}$-inch chain. Because of this sizing error, hexagonal-link and round-link sizing chains were examined for sizing accuracy.

Figure 13 shows that performance was not improved by use of round and hexagonal links in the sizing chains. In this chart, sizer effectiveness is measured by dividing the number of fruits that passed through the links by the actual number of small fruits in the sample. The problem of large fruit passing diagonally through the square openings, as indicated by average values above 1.0 in figure 13, was partially solved by the hexagonal-link chain and completely solved by the round-link chain. The values below 1.0 for sizer effectiveness in figure 13 show that fruit passing through the round and hexagonal links was of smaller diameter than the chain openings. But these chains created a new problem which accounted for the lower effectiveness shown in figure 13. The hexagonal and especially the round-link chain had webbed areas between the link openings which caused many small fruits to be carried under the device without contacting a link opening. Also, the round- and hexagonal-link chains did not submerge the incoming fruits nearly as well as the square-link chain, so a separate introduction device would be required.

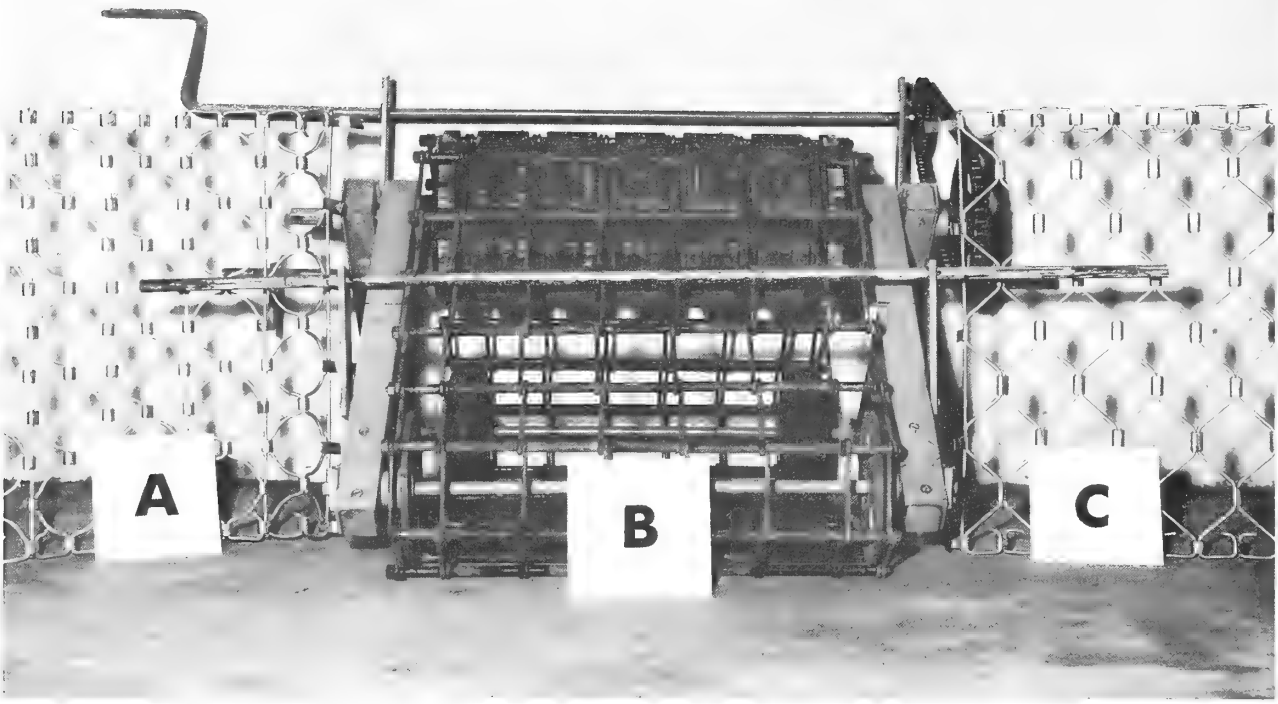

FIGURE 11.—Three shapes of chains tested for the underwater sizing of apples: (A) circular, (B), square, and (C) hexagonal.

Sizer accuracy was not greatly decreased by increased speed of chain movement up to 46 f.p.m.

Of the four sizers tested, the chain sizer was the only satisfactory device for a high-capacity system. The square-link chain appeared satisfactory for accuracy, introduction-submersion characteristics, and potential capacity in these preliminary trials.

Testing of Pilot Model Hydrosizer

A sizing mechanism (fig. 14) similar in design and construction to the test mechanism previously described, was installed in the laboratory test tank. It was constructed so that it could be fitted with a square-link chain having openings of 2¼, 2¾, or 3¼ inches, or with a hexagonal chain with openings of 2¾ inches. The sizing unit was driven hydraulically. Two chain speeds were employed: "fast", in which the linear translation of the chain was approximately 64 f.p.m., and "slow", approximately 37 f.p.m. The water flow in the tank was adjustable; it was set so that the sizing device was kept nearly loaded with apples.

A typical test of the sizer was conducted as follows: (1) The water flow was established in the tank; (2) the test apples were placed in the water in the dump and feed area; (3) the sizer was started and operated until all apples were sized; and (4) the two sizes of fruit were accumulated and evaluated for quality.

Fruit Bruising

Studies of fruit bruising were made with McIntosh apples initially bruise-free. The apples were individually selected on the tree, placed on plastic cup-trays in shallow wooden boxes, and

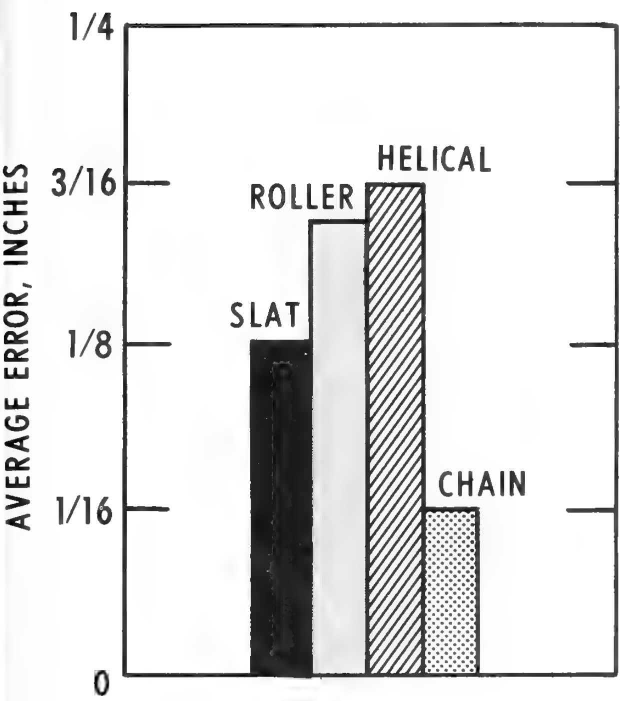

FIGURE 12.—Sizing error in transverse diameter of medium size McIntosh apples with four types of hydrosizers.

stored at 32° F. They were reexamined for mechanical blemishes before use as test samples and, if bruised, were either discarded or marked with indelible ink on the blemishes.

Many trial runs were made with the 2¾-inch square-link chain before smooth operation and uniform feeding of the sizer were obtained. Smooth operation of the chain proved essential since a slight vertical movement of the chain caused the apples to roll and bounce under water from one crossbar of the chain to another. The vertical movement was finally eliminated by installing underwater wooden guides to support the chain underwater. The angle of submergence of the chain was adjusted to 19.6° since this seemed to give the best and most consistent carry of the fruit through the sizing operation (see fig. 14). Tests with the 2¼-inch and 3¼-inch square-link chains were made at the same angle of incline. Installing flights of rubber tubing ⅝ inch in height on the 2¾-inch chain at intervals of three or four links proved helpful in preventing the large apples from rolling across the chain crossbars.

The McIntosh apples employed in the bruise study with the 2¾-inch square-link chain averaged 14 pounds pressure in flesh firmness; those used later for the other two sizes of chain had a firmness of approximately 11 pounds. In most tests, apples of another variety were mixed with the bruise-free McIntosh to provide an adequate volume of fruit for representative operation of the sizer. Damage was assessed after holding the fruit several days at 70° F. following the sizing operation.

Complete freedom from skin breaks and bruising, except for "chain marks," was attained with the sizing equipment. The chain marks were flesh indentations no greater than ⅛ inch in width, usually ½ inch in length but never more than 1 inch, and of slight depth (approximately $\frac{1}{16}$ inch). Many apples were free of these marks, but up to 10 marks were observed on individual fruits. The average numbers of such bruises are summarized in table 7 for the several test conditions employed.

The chain sizer of greatest dimension (3¼ inches) proved less damaging than the smaller chains, probably because there was less rolling of

TABLE 7.—*Average number of bruises (chain marks) on McIntosh apples due to chain sizing in water, by size of square-link chain opening and rate of chain travel*

Size of square-link opening and speed of chain	Bruises per fruit on—		
	Small apples [1]	Large apples [2]	All fruit
2¼ inches:			
37 f.p.m.	[3] 0	2. 3	2. 2
64 f.p.m.	[3] 0	3. 2	3. 0
2¾ inches:			
64 f.p.m.	0. 4	2. 4	1. 7
3¼ inches:			
37 f.p.m.	1. 0	2. 0	1. 2
64 f.p.m.	1. 3	[3] 1. 5	1. 3

[1] Apples which passed through the sizer openings.
[2] Apples which did not pass through the sizer openings.
[3] A small number of fruits of this size were used in these tests.

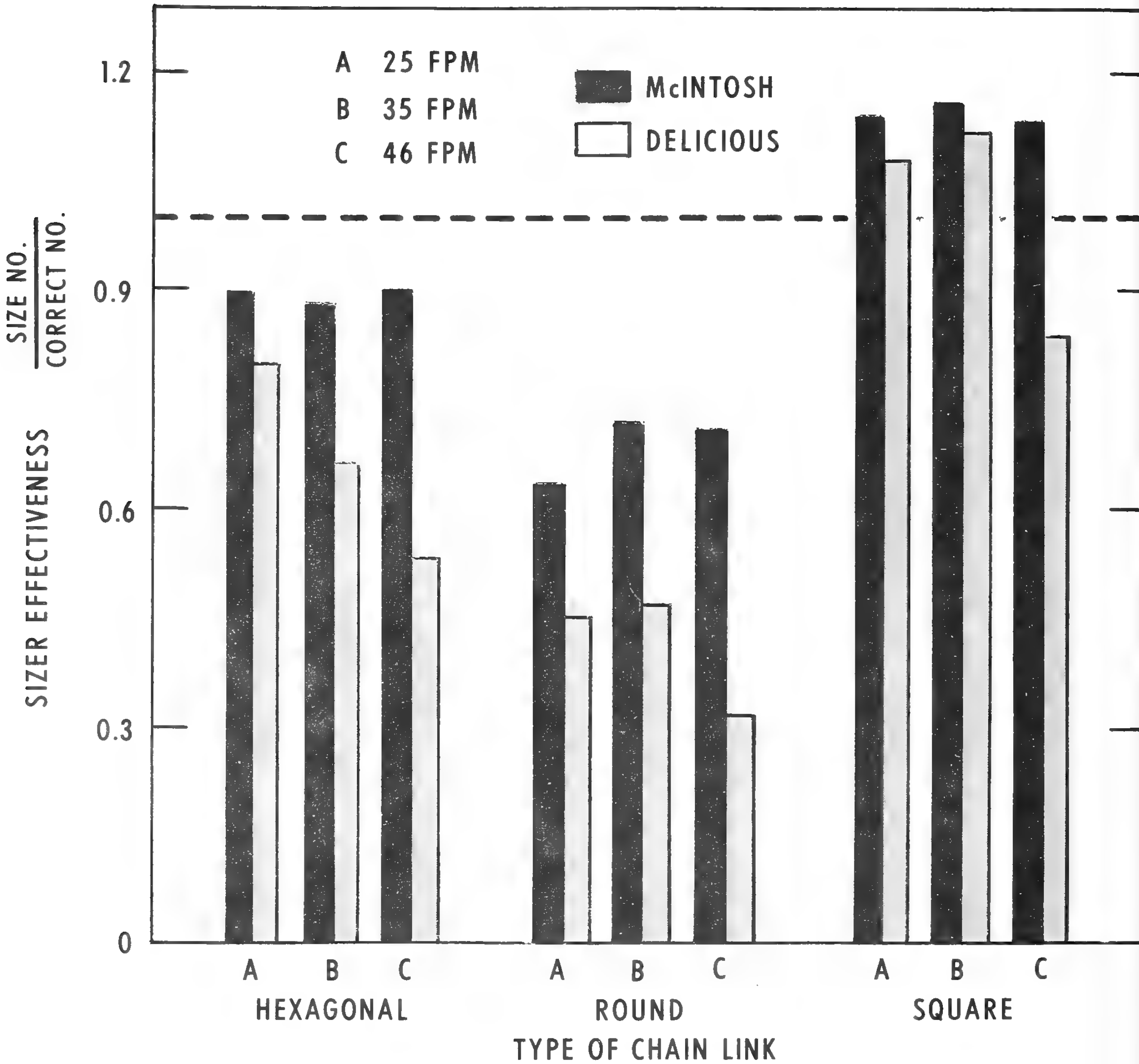

FIGURE 13.—The effect of chain type and speed of translation upon sizing accuracy for McIntosh and Delicious apples.

the apples across the bars and a large percentage of the fruit passed through the openings. It may be noted that "small" apples were damaged less by the smaller chains than apples which did not pass through the chain openings. On this basis, it would seem desirable to remove the largest apples first and the smallest apples last from a sizing system.

The extent of bruising, as recorded in table 7, is probably of minor significance to the market quality and condition of the fruit. When evaluated on the basis of surface area affected (*4*) as shown in table 8, seven marks, one-eighth inch wide and one-half inch long, would about equal the area classified as slight bruising (0.43 square inch). With the good operating conditions obtained in the tests after the underwater wooden guides were installed, it was uncommon to find more than 3 percent of the fruit with seven or more chain marks, and therefore slightly bruised.

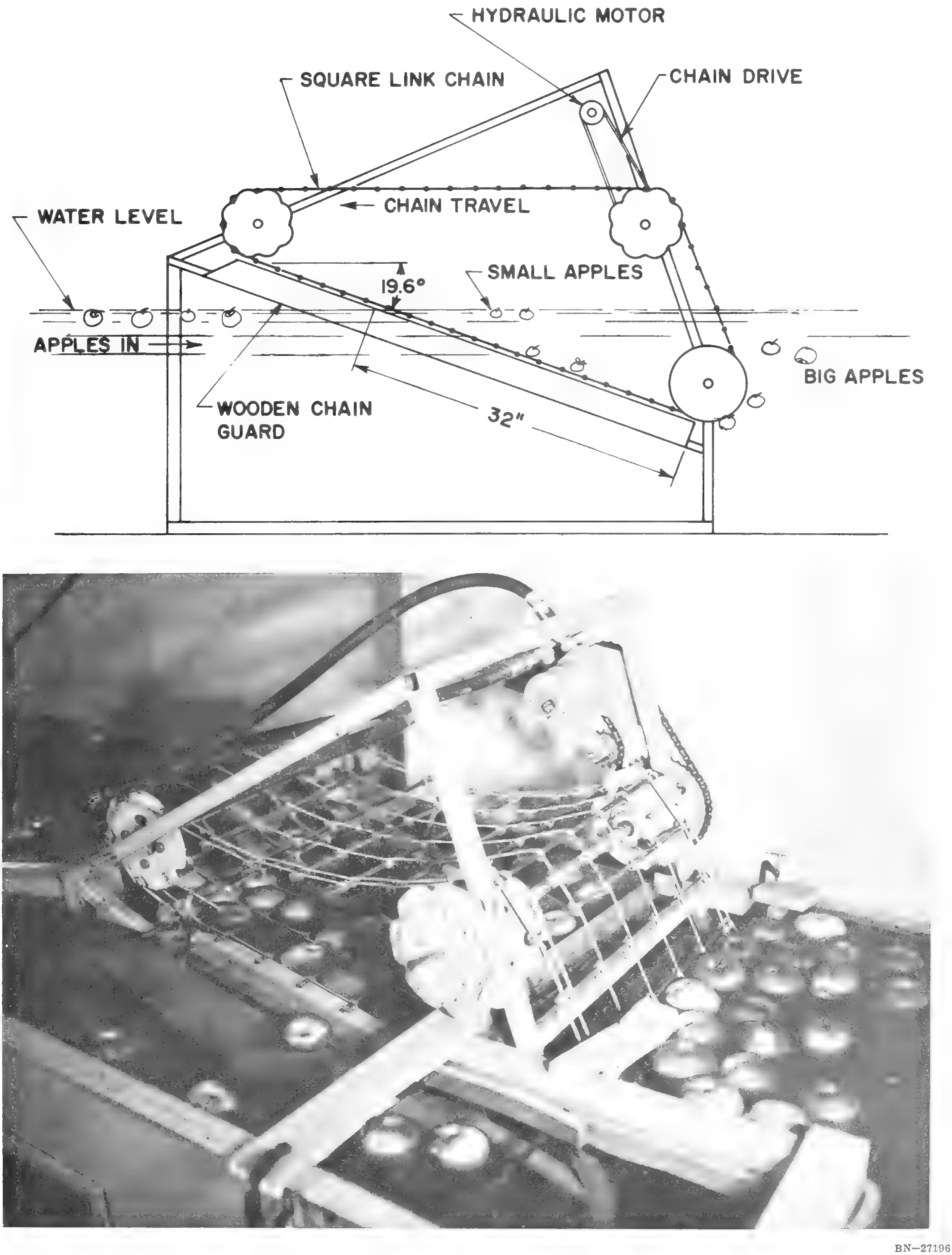

FIGURE 14.—Diagram and photograph of pilot model chain hydrosizer.

TABLE 8.—*Standards of bruise damage according to affected surface area of the fruit* [1]

Bruise classification	Minimum area affected	
	Single bruise	Multiple bruises
	Square inch	*Square inch*
Slight	0. 20	0. 43
Moderate	. 44	. 75
Serious	. 76	1. 23

[1] Adapted from Burt (*4*).

Sizing Accuracy With Square-Opening Chain

Rate of chain travel and number of passings.—Orchard-run McIntosh apples of various sizes were employed to ascertain the accuracy of the square-link sizing equipment. Three bushels of fruit were supplied to the sizer chain to keep it completely loaded during a test. Accuracy of the 2¾-inch sizing chain was based on the assumption that it would separate the fruit into two size groups; namely, fruit of 2¾ inches maximum diameter and larger, and fruit of less than 2¾ inches maximum diameter. The results of eight test runs using the same fruit are summarized in table 9.

The maximum operating speed of the chain, 64 f.p.m., was used in tests 1 through 5. A single pass of the fruit through the sizer resulted in 23.1 to 34.9 percent of the apples being placed into the wrong size group according to their maximum diameter as measured by a sizing ring. The maximum accuracy was usually attained after the second sizing, in which the fruit carried under the chain the first time was rerun. A third sizing usually increased accuracy slightly, but primarily at the expense of "losing" larger fruit to the small-size group.

A slower rate of travel of the chain, 37 f.p.m. in tests 6, 7, and 8, greatly increased the sizing accuracy of the equipment. A single passing of the fruit yielded an accuracy similar to three passings at the higher rate of chain travel. Repeated passings of the larger fruit (test 6) did not improve the accuracy at this speed.

Removal of all fruit 3 inches and larger in diameter prior to running the apples through the sizer tended to decrease the accuracy at the slower chain speed.

TABLE 9.—*Percentage of McIntosh apples incorrectly sized by intermediate (2¾-inch) square-link chain sizer*

Chain speed, apples used and number of times apples were passed under the chain	Actual size of apples		Total incorrectly sized
	2¾-in. diameter and larger	Less than 2¾-in. diameter	
64 f.p.m.			
Orchard run:			
Test 1:	*Percent*	*Percent*	*Percent*
1 pass	3. 5	22. 9	26. 4
Test 2:			
1 pass	5. 4	21. 1	26. 5
2 passes	7. 2	8. 9	16. 1
3 passes	9. 0	6. 2	15. 2
Apples 3 inches in diameter and larger removed:			
Test 3:			
1 pass	4. 4	30. 5	34. 9
2 passes	5. 6	13. 1	18. 7
3 passes	6. 9	9. 7	16. 6
Test 4:			
1 pass	2. 5	20. 6	23. 1
2 passes	5. 6	10. 9	16. 5
3 passes	6. 3	7. 0	13. 3
Test 5:			
1 pass	1. 9	26. 9	28. 8
2 passes	3. 2	12. 2	15. 4
3 passes	4. 6	7. 1	11. 7
37 f.p.m.			
Orchard run:			
Test 6:			
1 pass	2. 5	9. 0	11. 5
2 passes	4. 5	5. 9	10. 4
3 passes	7. 0	4. 3	11. 3
Apples 3 inches in diameter and larger removed:			
Test 7:			
1 pass	4. 4	12. 9	17. 3
Test 8:			
1 pass	4. 4	12. 1	16. 5

It is believed that the quantity of fruit misplaced with a single sizing operation at the slower rate of chain travel would not be a serious error in the commercial sizing of fruit that is to be placed in storage and resized upon preparation for marketing. Most of the error in sizing was

due to small fruit failing to pass through the chain openings.

The square-link chain was found to have definite limitations for accuracy in sizing due to the variations in fruit shape and in fruit position at the openings.

Chain sizes and fruit varieties.—Comparisons for sizing accuracy of the several chain sizes and of varieties or fruit lots required previous size classification of the apples. For this purpose, sections of each sizing chain were employed to select the apples of various sizes to be used for testing the hydrosizing equipment. The following categories of fruit sizes were used:

Class 1. Apples of diameter less than one-fourth inch smaller than the designated chain size. These apples should always pass through the chain openings.

Class 2. Apples larger than class 1, but small enough to pass through the chain openings regardless of how positioned to the opening.

Class 3. Apples with a maximum diameter greater than the chain openings, but which could pass through a chain opening due to a smaller minimum diameter.

Class 4. Apples that could not pass through the chain openings regardless of position.

Apples of classes 1 and 2 are smaller than the chain opening; those of classes 3 and 4 are larger than the chain openings. Those of class 4 will never pass through the chain openings. Thus, errors in separation of fruits of classes 1, 2, and 3 reflect the accuracy of the equipment. A standard number of apples of each of classes 1, 2, and 3 were used, and comparisons were made by counting the number improperly sized. Class 4 apples were incorporated in the test lots to simulate actual sorting operations.

Each test lot of fruit consisted of a similar number of apples (usually 100) of each size classification. The apples were painted with a different color for each classification and recombined for the sizing tests.

Two rates of travel were employed for each size of chain; namely, 37 f.p.m. ("slow") and 64 f.p.m. ("fast"). Each test consisted of three replications, and fruit was passed through the sizing equipment three times for each replication. Fruits which did not pass through the chain openings the first time were sized again. A third passing was made with fruits which did not go through the chain openings on either of the first two passings.

The results presented in table 10 are expressed as percentages of the large and small fruits that were misplaced. The data for the group "small apples misplaced" are for apples of classes 1 and 2 which did not pass through the sizer openings. The "large apples misplaced" values are for class 3 apples which were misplaced by passage through the sizer openings. Apples of class 4 were not considered in obtaining these percentages since none could possibly pass through the chain.

A slow rate of chain movement in most instances provided opportunity for more complete sizing of the small apples than the fast operation. On the other hand, the slow rate of translation usually permitted more of the large apples (class 3) to pass through the openings and be misplaced than the fast operation. The net effect (mean) was a similar accuracy in sizing at the two rates of translation.

For both rates, the mean accuracy was about the same for one, two, and three passings of fruit through the sizer. The misplacement of small fruits was decreased by increasing the number of passings, whereas the loss of large fruit was increased.

Sizing Accuracy With Hexagonal-Opening Chain

Since a large percentage of the fruit was sized inaccurately by the square links, it seemed desirable to further evaluate a chain sizer with hexagonal openings. A chain with 2¾-inch openings was installed. Jonathan and Delicious apples previously sized with the square-link chain openings were tested. The results are summarized in table 11. The earlier difficulties encountered with the hexagonal chain in submerging and carrying the fruit through the sizer were overcome by employing a constant supply of fruit so as to keep the chain nearly loaded.

Direct comparisons for sizing accuracy for the Jonathan variety show the hexagonal chain was considerably more accurate than the square-link chain. This was true at the slow as well as at the fast rates of travel. Also, both large and small apples were sized more accurately with the hex-

TABLE 10.—*Percent of small and large apples misplaced in hydrosizing, by size of square-link chain, apple variety, and rate of travel of the chain*

Size of apples and pass number	2¼ inches		2¾ inches				3¼ inches			
	Delicious		Golden Delicious		Jonathan		Delicious		McIntosh	
	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
Small apples misplaced:[1]	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1 pass	18. 0	44. 8	14. 3	35. 7	5. 0	20. 2	12. 5	26. 0	5. 7	11. 7
2 passes	5. 2	22. 3	5. 2	16. 0	1. 7	4. 5	3. 9	6. 4	1. 5	1. 7
3 passes	2. 2	13. 2	3. 0	10. 3	. 8	2. 0	2. 0	1. 9	1. 0	. 2
Large apples misplaced:[2]										
1 pass	23. 3	11. 7	18. 0	9. 3	25. 3	21. 6	30. 6	22. 9	27. 9	31. 6
2 passes	35. 0	20. 0	27. 0	18. 7	45. 2	43. 5	47. 2	34. 6	46. 5	48. 0
3 passes	45. 7	26. 3	32. 3	35. 7	54. 0	57. 0	61. 2	47. 0	53. 9	64. 8
Mean:										
1 pass	20. 7	28. 3	16. 2	22. 5	15. 1	20. 6	21. 5	24. 5	16. 8	21. 7
2 passes	20. 1	21. 3	16. 1	17. 3	23. 4	24. 0	25. 5	20. 5	24. 0	24. 8
3 passes	23. 9	19. 7	17. 7	18. 0	27. 4	29. 5	32. 0	24. 4	27. 4	32. 5

[1] Apples of classes 1 and 2 (see text).
[2] Apples of class 3 (see text).

TABLE 11.—*Percent of small and large apples misplaced in hydrosizing with 2¾-inch hexagonal-link chain, by apple variety and rate of travel of the chain*

Size of apples and pass number	Jonathan		Delicious	
	Slow	Fast	Slow	Fast
Small apples misplaced:[1]	*Percent*	*Percent*	*Percent*	*Percent*
1 pass	3. 2	11. 9	2. 4	18. 3
2 passes	. 7	3. 0	. 0	5. 4
3 passes	. 3	. 8	. 0	1. 7
Large apples misplaced:[2]				
1 pass	12. 1	14. 1	16. 0	6. 8
2 passes	22. 7	22. 7	21. 7	14. 5
3 passes	34. 1	29. 0	27. 3	21. 3
Mean:				
1 pass	7. 7	13. 0	8. 8	12. 6
2 passes	11. 7	14. 5	10. 9	10. 0
3 passes	17. 3	14. 9	13. 7	11. 5

[1] Apples of classes 1 and 2 (see text).
[2] Apples of class 3 (see text).

agonal chain. The similarity in shape of Golden Delicious and Delicious apples permits a degree of comparison, and again, the hexagonal chain gave better sizing accuracy than the square-link chain. These results with the pilot equipment do not agree with the preliminary results (see fig. 13). Apparently the operational conditions in the pilot model overcame the difficulties of fruit rolling and proper positioning of the apples to the openings experienced in the preliminary tests.

The tests with the pilot model chain sizer indicated that a single passing of apples beneath a submerged chain with hexagonal openings should provide a satisfactory method of hydrosizing. This system should be incorporated into a prototype model for further evaluation.

Pallet Box Fillers

Recently developed mechanical devices for filling pallet boxes (*3*, *6*) have proven satisfactory for firm varieties of apples which are more tolerant to bruising than the McIntosh. It was believed that mechanical damage to apples in filling

into pallet boxes might be further reduced by utilizing water as a medium. Also, a high-capacity filler is needed for a presizing and presorting operation. For these reasons, much attention was directed to developing and testing hydrofillers. Three types were examined: (1) Flume, (2) direct fill, and (3) accumulator.

Apparatus

The flume-type filler consisted of a plexiglass trough 10 inches wide that was inclined lengthwise into a 1-bushel box that was partially submerged in water. The apples flowed in water down the trough and into the box. The water level in the box was lowered by manually elevating the box as it filled with fruit.

The direct-fill device placed an empty bushel box about two-thirds submerged in water on its side. The frame which held the box also held a sloping cover partially over the open side of the box so as to provide an enclosure with the box for accumulating fruit from a submerging conveyor (fig. 15). Filling was completed by rotating the box and cover to the upright position and raising the whole device from the water. The filled box was then removed sideways from the frame and cover.

The accumulator type of filler was tested by submerging an empty bushel crate in an inverted position into a tank of water. It was then filled with fruit from a flighted rubber belt submerging conveyor which carried the apples below the water surface and under the open side where they were released to float upward into the inverted container. When full, the crate was placed directly over an upright submerged crate and both were elevated from the water. As the upper crate moved above the water surface, all apples trans-

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FIGURE 15.—Direct-fill type of box filler in operation.

ferred from the upper inverted crate to the lower upright crate. The filled lower crate was then removed. The accumulator-type device, mounted within a glass-sided tank and slightly elevated so that the apples are beginning to move into the lower crate, is shown in figure 16. The upper accumulator crate shown here was reduced $1\frac{1}{2}$ inches in lateral dimensions to facilitate fruit transfer to the lower crate; also, the slats of both were narrowed to permit a better view of the apples.

Performance Tests

Each of the three filling devices was tested using one bushel of McIntosh fruit. The primary objective was to develop general principles of opera-

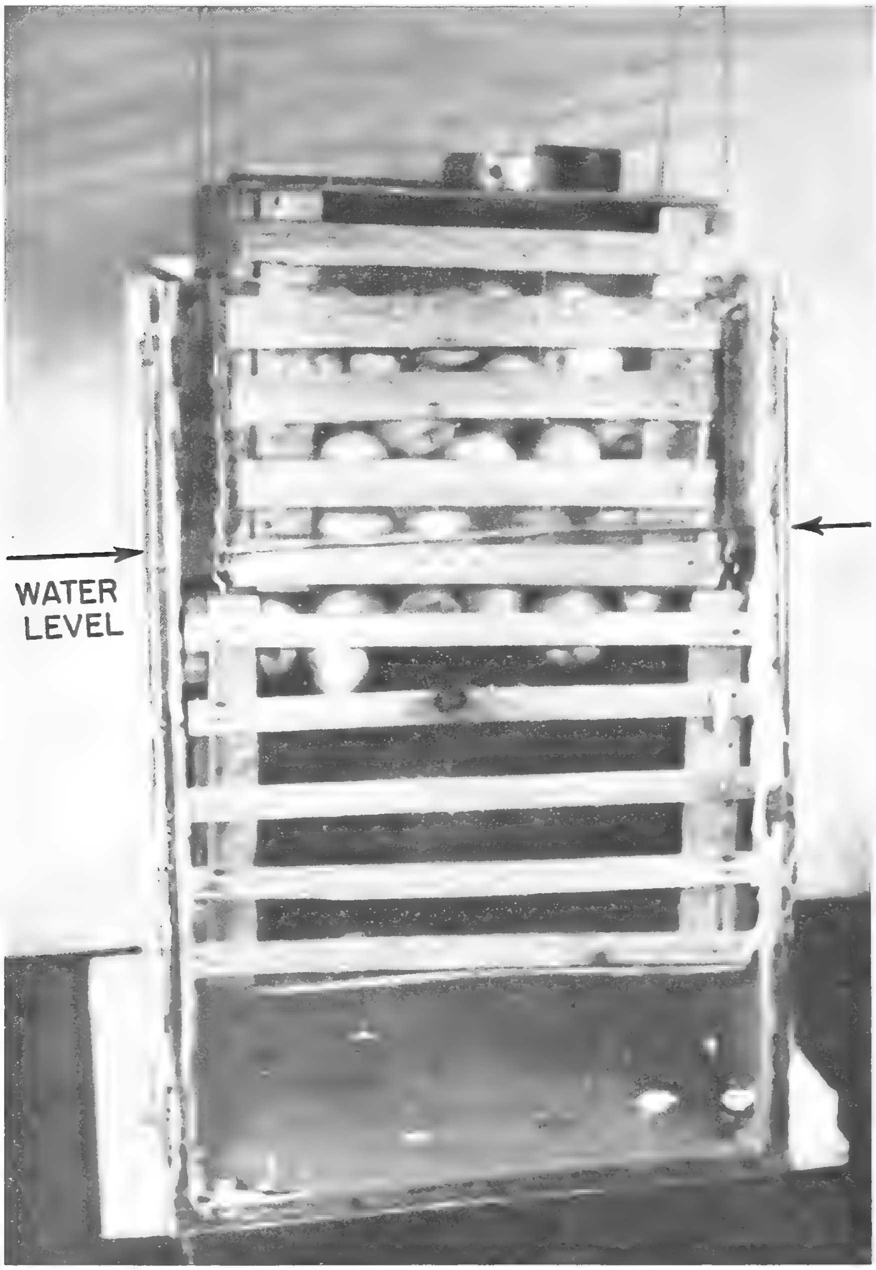

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FIGURE 16.—Hand operated accumulator box (top) filled with apples ready for transfer to field box (bottom).

tion for a hydrofiller. Performance of the direct-fill device was observed through the side and bottom windows of the test tank.

Results and Discussion

The flume-type filler utilizing waterflow accompanying the fruit down a gently sloping flume to fill the box appeared unsatisfactory because of bruise damage. Even when the water level was carefully controlled in the box, fruit coming into the box struck stationary fruit which was buoyed up by the 8 to 10 inches of submerged fruit below this top layer. The impact bruising which occurred seemed as severe as if there were no water supporting the fruit in the box.

Tests of the direct-fill device were quite successful except for one major problem—keeping *all* of the fruit in the box when it was removed from the water. This problem was partially solved by moving the point of rotation to a higher location so that the box and frame rose out of the water as they were rotated to the box removal position. A mechanically operated gate to close the filling opening was needed to completely solve the problem, and this severely damaged any fruit caught between the gate and box-holding frame. Further modifications are needed before this box-filling method will be satisfactory.

The accumulator method was quite successful when the accumulator box was 1 to 2 inches smaller in lateral dimensions than the box being filled. Tests using a stationary accumulator which enclosed the bushel box and held down the fruits floating above the box proved unsatisfactory because fruits were carried up by the box edges and corner posts and frequently wedged between the accumulator and box sides. The tests using a smaller accumulator box which was raised from the water with the bushel box were very satisfactory.

Pilot Model Hydrofiller

The accumulator method appeared superior to others in all respects except cost and space requirement. Essentially it consists of a submerging conveyor and a partly submerged chamber open at the top and bottom for accumulation of the fruit. Once filled, the accumulator is moved horizontally over the fruit container and both are lifted vertically to transfer the fruit to the box. A sketch of the proposed full-size hydrofiller is shown in figure 17. Two accumulator boxes are used. This hydrofiller would allow continuous operation of the submerging conveyor, thus providing high potential capacity. Its operation can best be explained by the following list of operations in a cycle:

1. Accumulator box filled by submerging conveyor;
2. Both accumulator boxes roll to put one in hoisting position, the other in filling position;
3. Hoisting mechanism raises both accumulator box and pallet box out of the tank, transferring fruit to the pallet box;
4. Full pallet box rolls off the hoist and an empty box rolls on;
5. Hoist lowers both accumulator and empty pallet boxes;
6. Empty accumulator box rolls into filling position and other accumulator box, now filled, rolls into hoisting position on the other hoist.

It is anticipated that any type of water filling would leave more cavities and generally give a poorer fill than air-gravity filling of boxes. Attempts to use vibrations and turbulent waterflow through the boxes during fruit transfer proved unsatisfactory in giving a better fill. Further work should be done to solve this problem because, although cavities may increase fruit cooling rate, an estimated 10 percent of storage capacity will be lost.

Fruit Bruising Tests of Pilot Model Hydrofiller

The pilot model accumulator system for the hydrofilling of 1-bushel field crates installed in the laboratory test tank is pictured in figures 18 and 19. Numerous filling tests and equipment modifications were made to increase the efficiency of operations and to eliminate the possibilities of mechanical injury to the fruit.

A major problem in filling a box in water is the slack fill of the container due to the buoyancy of the fruit, allowing bridging and preventing the settling of the apples as filling progresses. A 1-bushel container filled underwater held 17 percent less fruit than a dry-filled container. Two

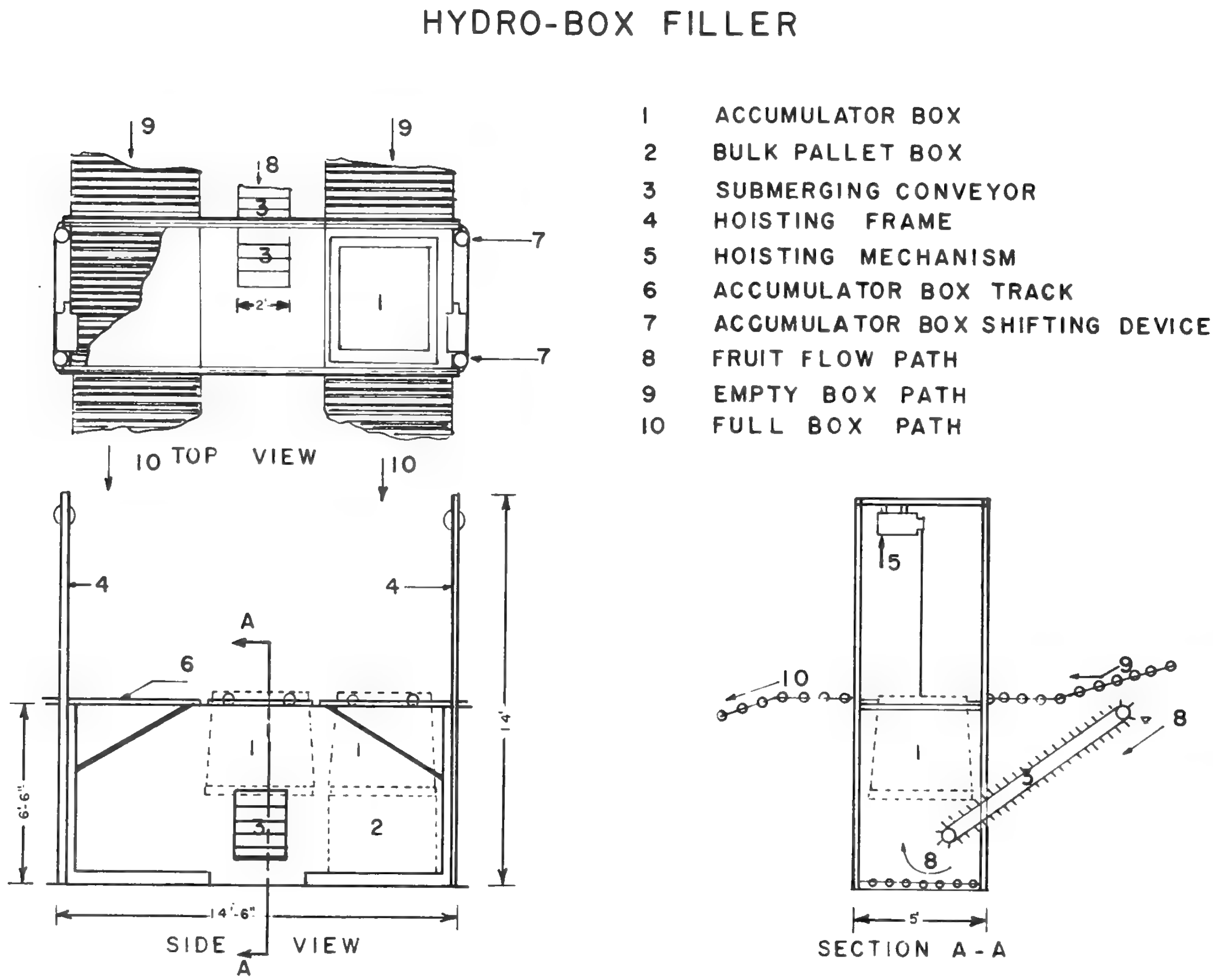

FIGURE 17.—Sketch of proposed hydrofiller of accumulator type for filling bulk boxes with apples.

questions are unresolved; namely, what is the capacity reduction factor for 16- to 20-bushel pallet boxes, and how much bruising will occur with the subsequent lift truck handling of hydrofilled containers. Underwater filling of pallet boxes could not be examined with the equipment available.

Twenty-five bruise-free McIntosh apples were mixed with Rome Beauty apples of approximately the same size to make up 1-bushel lots for studies of bruising during the filling of the bushel box. Bruise damage was evaluated on the basis of affected surface area as shown in table 8. Stem punctures were recorded by counting the affected fruit. The results of filling 4 bushels of fruit by the accumulator method were:

Type of damage	*Percent of fruit*
Slight bruising	4.5
Moderate bruising	0
Serious bruising	1.1
Stem punctures	2.2
Total commercial damage	7.8
Bruising less than slight	38.2
Total damage	46.0

The bruising recorded might have occurred during pickup of the fruit from the water surface, during conveying of the apples underwater by the conveyor belt, during the accumulation in the accumulator, or during the transfer of the apples to the bushel crate upon removal from the

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FIGURE 18.—Pilot model hydrofiller ready for operation. The apples have been placed in the feed area to the submerging conveyor. The filling accumulator, constructed of plexiglass, and apple container (at upper right) will be submerged and the accumulator placed to receive the apples from the submerged end of the conveyor.

water. The prevalence of long-narrow bruises suggested some damage resulted from contact with the sharp edges of the accumulator. These edges were padded with foam rubber for subsequent runs.

The above data may be compared to the results obtained by Burt (*4*) from tests in which 1-bushel boxes were filled with an automatic box filler. For McIntosh of 14.5 pounds firmness, 4.7 percent of the apples were slightly bruised, 0.2 percent moderately bruised, and none seriously bruised. For softer fruit (9.5 pounds) 5.1 percent were slightly bruised, 1.3 percent moderately bruised, and none were seriously bruised. Although hydrofilling, as used here for 1-bushel boxes, seemed to offer no advantage over dry filling in the prevention of bruising, it would possibly offer considerable advantage in filling bulk boxes.

In a second series of tests, 4 bushels of mixed fruit filled by the hydrosystem were compared for bruising with 4 bushels filled by hand. The latter was accomplished by rapidly picking up several fruit at a time with each hand from a tabletop surface to simulate conditions in commercial packinghouses. According to the data summarized in table 12, the two filling methods gave equivalent fruit damage except in the category of less-than-slight bruising. It is therefore believed that hydrofilling by the accumulator method would be commercially acceptable.

Conclusions

Water flotation dumpers utilizing the submergence principle, as now commercially available, are recommended for the unloading of apples from pallet boxes.

Sorting fruit in water at present offers no advantage over modern sorting methods. The float-roll sorting table employed out of water is recommended because of its high capacity and efficiency.

Of the several sizing methods examined, the chain-type sizer running partially underwater proved best for hydrosizing apples, because it gave positive fruit flow and offers a potential of high capacity. Apples may be chain-sized underwater without appreciable bruises and skin breaks with the chain moving at rates up to 64 f.p.m.,

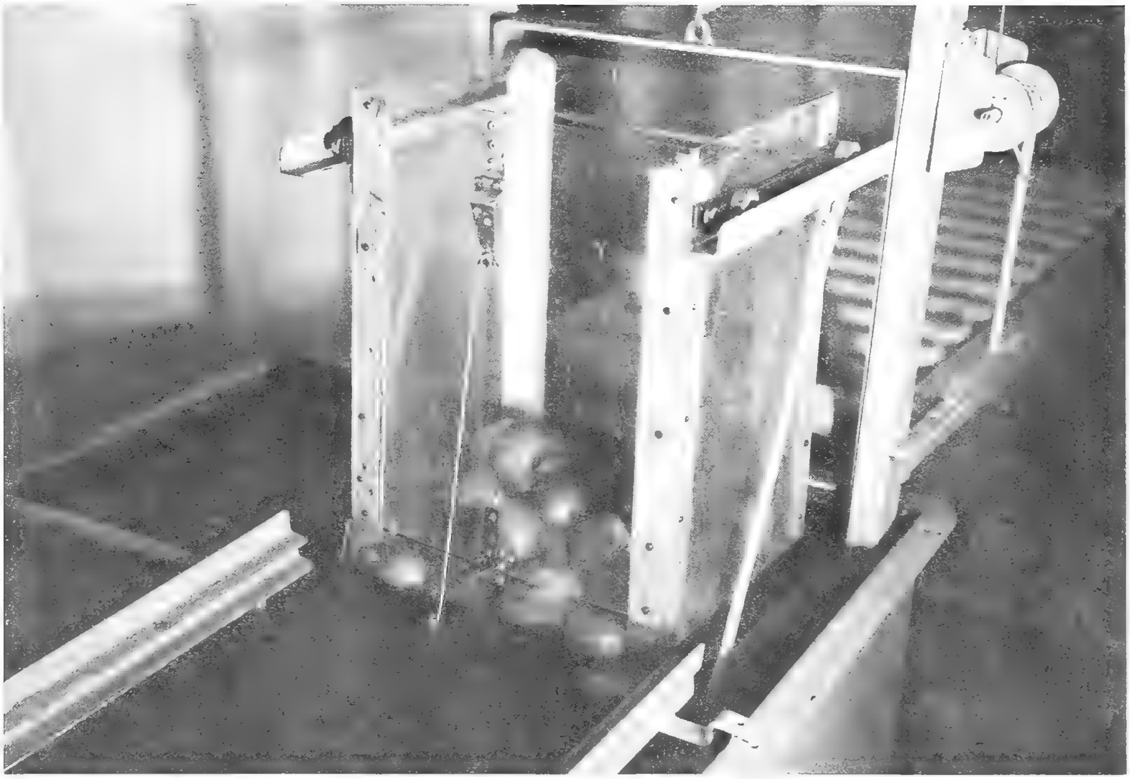

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FIGURE 19.—The accumulator of the hydrofiller has been partially raised to transfer fruit to the apple container which is directly beneath the accumulator, but not visible in the water.

TABLE 12.—*Percent of McIntosh apples damaged by hydro-filling and hand-filling of bushel crates* [1]

Type of damage	Hydro-filling	Hand-filling
	Percent	*Percent*
Slight bruising	2. 9	3. 2
Moderate brusing	. 0	. 0
Serious bruising	1. 9	. 0
Stem punctures	1. 0	2. 1
Total commercial damage	5. 8	5. 3
Bruising less than slight	35. 6	24. 2
Total damage	41. 4	30. 0

[1] Four bushels of apples were used with each type of filling; 104 McIntosh apples were in the hydro-filling test, and 95 in the hand-filling test.

provided the chain is run smoothly and the apples do not roll while under the chain.

Sizing accuracy with an underwater square-opening chain sizer is improved by reducing the rate of travel of the chain and by two passings of the fruit through the sizer. A sizer with hexagonal-shaped openings gives a better sizing accuracy with a single passing of fruit than the square-link chain with two passings.

The hexagonal-opening sizer is recommended for use at rates of travel up to 50 f.p.m., with an angle of incline no greater than 20 degrees, and with a constant supply of fruit.

Three types of hydrofillers were developed and examined, and of these, the accumulator type seems the most suitable for consideration as a pallet-box filler. It is relatively simple in design and operation and, according to tests with a pilot model filler of 1-bushel capacity, should handle the fruit in a relatively gentle manner.

Containers loaded underwater have a slack fill upon transfer to air because of fruit bridging and poor nesting while underwater. This problem needs investigation, especially in respect to possible bruising damage, with bulk containers.

PROPOSED HYDROHANDLING SYSTEM

A practical system for hydrohandling apples during preparation for storage in pallet boxes seems feasible. The experimental results reported here, together with the numerous ideas, suggestions, and comments of researchers, machinery manufacturers and representatives, and packinghouse operators, were considered in developing a system plan.

A hydrohandling system would require considerable space, but this is relatively unimportant because it could be located outdoors, preferably adjacent to a warehouse with existing facilities for electricity, water, and drainage. Portions of the system would be roofed-over for protection of workmen against sun and rain. Paving would be required for the operation of lift trucks and other mobile equipment and for the stacking of empty and filled boxes.

A plan view of a proposed system to handle 600 bushels per hour of orchard-run fruit and yield three sizes of sorted fruit loaded into bulk boxes is presented in figure 20. Alterations of the plan are feasible to fit the needs of a particular storage plant. A paved area approximately 60 by 90 feet surrounding the system would allow a 15-foot perimeter for lift truck operation. This area might be reduced somewhat by careful planning and integration with existing paved areas.

Orchard-run apples in bulk boxes, received at the left-hand end of the system, proceed through the system in the sequence shown in the diagram.

1. **Dumper.**—A hydrodumper of current commercial manufacture and of high fruit capacity removes the apples from the pallet boxes. The apples progress toward the right-hand end of the dumper and toward the elevator conveyor by a forced current of water.

2. **Elevator conveyor.**—The fruit is elevated from the water of the dumper by a roller conveyor. An overhead water spray over the conveyor removes loose dirt and debris from the apples.

3. **Eliminator.**—A standard type, out-of-water, square-link rubber chain removes the small fruit.

4. **Spreader belt.**—The apples, still out of water, are spread out for transfer to the sorting table.

5. **Sorting table.**—A float-roll sorting table is utilized for removal of defective and poorly colored fruit by workmen.

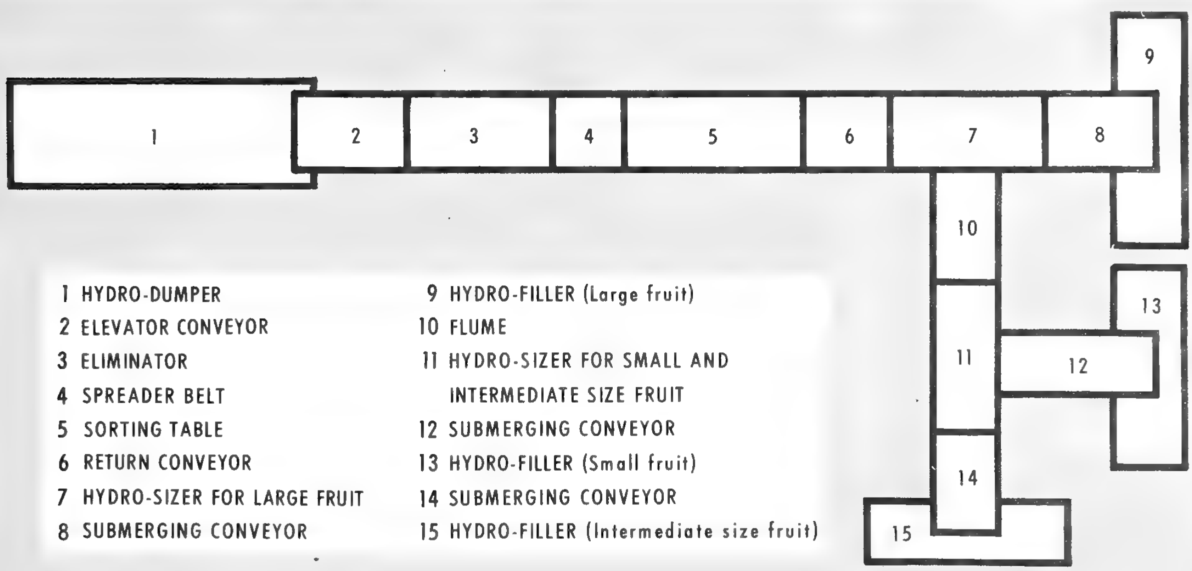

FIGURE 20.—Layout of a proposed hydrohandling system for sorting and sizing apples and filling them into pallet boxes for storage.

6. **Return conveyor.**—The apples move into water by means of a roller conveyor.

7. **Hydrosizer for large fruit.**—The large apples carry beneath the hexagonal-opening chain sizer and move on to the submerging conveyor (8). The smaller apples go through the chain openings and float away to the right in a water current to another hydrosizer (11).

8. **Submerging conveyor.**—The large apples move below the water surface into the box filler.

9. **Hydrofiller (large fruit).**—An accumulator type of filler accumulates a box of fruit, which is then transferred to a bulk box and taken away by a lift truck.

10. **Flume.**—The smaller fruits from the first sizer (7) move by water current to the next sizer.

11. **Hydrosizer for small and intermediate-size fruit.**—The small apples pass through the chain openings and float in a current of water to the submerging conveyor (12) and hydrofiller (13). The fruits of intermediate size pass beneath the chain, return to the water surface, and move to the submerging conveyor (14) and hydrofiller (15).

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